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RESEARCH MEMORANDUM

PERFORMANCE COMPARISONS OF NAVY JET MIX AND MIL-F-5624A (JP-3) FUELS IN TUBULAR AND ANNULAR COMBUSTORS

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NATIONAL ADVISORY COMMITTEE
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SUMMARY

An investigation was conducted to compare the performances of Navy Jet Mix and MIL-F-5624A (JP-3) fuels in single combustors from current turbojet engines. The Navy Jet Mix fuel used was composed of three parts MIL-F-7914, grade JP-5 fuel and one part unleaded MIL-F-5572 fuel. Combustion efficiencies and altitude operational limits were determined with both fuels in the J33, J35, J47, and NACA experimental annular combustors in a range of altitude from 20,000 to 60,000 feet and engine rotor speed from 40- to 100-percent normal rated at a flight Mach number of 0.6. Carbon-forming tendencies of both fuels were determined in the J33 combustor.

The results indicate that the unleaded Jet Mix fuel could be utilized satisfactorily over the normal operating range in a number of representative current turbojet engines. Small (3 to 5 percent) positive or negative variations in combustion efficiency occurred between the two fuels but this variation depended on the particular engine operating condition. The Jet Mix fuel gave lower altitude limits than JP-3 fuel throughout the altitude-speed range investigated in the J33 combustor; however, with the other tubular combustors a difference in limits was obtained only in the low rotor-speed range. The variation in fuel type did not affect the altitude operational limits of the NACA experimental annular combustor. Excessive carbon deposition is not predicted for unleaded Jet Mix fuel although this property may be marginal. The aromatic content of this particular Jet Mix fuel was 13.4 percent; Jet Mix fuels containing higher percentages of aromatic constituents may give more carbon deposition. Also, the Jet Mix fuel tested did not contain the tetraethyl lead that would normally be present. The effects of the lead additive were not determined.

INTRODUCTION

Carrier-based jet aircraft operate on high-volatility, low-flash-point fuel which must, for safety reasons, be stored in protected, centrally located bunkers aboard the carriers. The capacity of these bunkers is much less than the capacity of the perimeter bunkers containing the necessary fuel-oil supply. The jet-fuel capacity could be increased and the frequency of refueling decreased by utilizing some of these perimeter bunkers for jet-fuel storage. Safety requirements permit only high-flash-point (above 140° F) fuel to be stored in these unprotected bunkers and such fuel would not perform satisfactorily or meet freezing-point requirements in present turbojet aircraft. If a special kerosene type fuel were obtained which would meet the high-flash-point safety requirements, this fuel could then be stored in perimeter bunkers and blended with carrier reciprocating-engine aircraft gasoline (MIL-F-5572, grade 115/145) as required. A blend of 75-percent high-flash-point kerosene fuel (MIL-F-7914, grade JP-5) and 25-percent aviation gasoline met the freezing-point requirements and was designated Jet Mix fuel. The utilization of this fuel is contingent upon the satisfactory operation of jet engines on a blend of this type.

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Investigations comparing the performance of Jet Mix fuel and other fuels in current turbojet engines and their combustors were conducted at the NACA Lewis laboratory. Results of studies in a full-scale J34 turbojet engine comparing Jet Mix and unleaded clear gasoline fuels are reported in reference 1. This report presents data obtained with Jet Mix and MIL-F-5624A (JP-3) fuels in several single-combustor test units, and evaluates combustion efficiency, combustion stability, and carbon deposition. The Jet Mix fuel used in this investigation was blended by volume from one part unleaded MIL-F-5572 fuel and three parts MIL-F-7914, grade JP-5 fuel. The blend did not contain the tetraethyl lead that would be introduced with leaded MIL-F-5572, grade 115/145 fuel used aboard carriers.

Combustion efficiencies and altitude operational limits of both fuels were determined in J33, J35, J47, and NACA annular combustors. The tubular combustors were standard production units all currently operated on MIL-F-5624A (JP-3) fuel; the NACA annular combustor is an experimental unit developed to operate on MIL-F-5624A (JP-3) fuel. The performance variables were determined in a range of altitude from 20,000 to 60,000 feet, engine rotor speed from 40- to 100-percent normal rated, and a flight Mach number of 0.6. Carbon-forming tendencies of both fuels were determined in the J33 combustor only and the results are presented and discussed in relation to the NACA carbon-deposition correlation used in reference 2.

APPARATUS AND PROCEDURE

The combustors used in this investigation were installed in the laboratory air-supply and exhaust ducting with valves located upstream and downstream to control air flow rates and pressures. Electric and gasoline-fired preheaters were used to control the combustor inlet-air temperatures. The detailed instrumentation and equipment features of the combustors used have been presented in previous NACA reports: the J33-A-23, the J35-C-3, the J47, and the NACA annular combustor, except for minor changes in air admission holes in the liner, in references 3, 4, 5, and 6, respectively.

Estimated combustor inlet-air conditions and combustor outlet-gas temperatures that were used to simulate engine operation at various altitudes and engine rotor speeds can be found for the J33, the J35, the J47, and the NACA annular combustors, in references 7, 4, 5, and 6, respectively.

The combustion efficiency values reported herein were computed as the ratio of the measured enthalpy rise of the fuel-air mixture across the combustor to the heating value of the fuel. A correction was made for the difference between the enthalpy of the carbon dioxide and water vapor in the burned mixture and the enthalpy of the oxygen removed from the air by the formation of the carbon dioxide and water vapor. The thermocouple indications were taken as true values of total temperature and no corrections were made for radiation or stagnation effects.

The data presented herein should not be used to compare combustor type and design because the values of combustion efficiency reported were, in some cases, obtained from a limited number of exhaust-gas temperature probes. However, the differences in performance obtained between the two fuels are considered sufficiently accurate as any temperature measuring errors would be present in both sets of data obtained with each combustor.

FUELS

The analyses of the fuels used in this investigation are shown in table I. The MIL-F-5624A (JP-3) fuel (NACA fuel 51-186) was a representative batch as received from the supplier and met the JP-3 fuel specification with the exception of the freezing point, which was 14° F too high. The Jet Mix fuel (NACA fuel 51-201) was blended by volume at the Lewis laboratory from one part unleaded MIL-F-5572 fuel (NACA fuel 49-167) and three parts MIL-F-7914, grade JP-5 fuel (NACA fuel 51-170). The unleaded MIL-F-5572 fuel was the base stock used in the preparation of grade 115/145, MIL-F-5572 fuel.

The unleaded Jet Mix fuel falls within MIL-F-5624A (JP-4) fuel specifications except that the freezing point is 16° F too high; therefore, the comparisons between JP-3 and Jet Mix fuel performance are applicable to comparisons between JP-3 and JP-4 fuel performance.

RESULTS AND DISCUSSION

Combustion Efficiency and Altitude Operational Limits 2428

The data obtained with several combustors and Jet Mix and JP-3 fuels are summarized in table II. The variation of combustion efficiency with simulated engine rotor speed for the two fuels is shown in figure 1 for each combustor investigated over an altitude range from 20,000 to 60,000 feet. Cross plots showing the effect of altitude on the combustion efficiencies of the two fuels at two constant simulated rotor-speed values are presented in figure 2. A comparison of engine altitude operational limits obtained with both fuels for all the combustors is presented in figure 3.

J33 combustor. - The combustion efficiency values obtained in this combustor with Jet Mix fuel are nearly as high as those obtained with JP-3 fuel throughout the altitude and rotor-speed range investigated, the maximum difference being approximately 3 percent (fig. 1(a)). An exception is the high simulated rotor speed and 60,000-foot altitude condition where the combustion efficiency of JP-3 fuel decreases very rapidly to a value about 10 percent lower than that of the Jet Mix fuel. The altitude operational limits with Jet Mix fuel are 7500 to 8000 feet lower than the limits with JP-3 fuel, as shown in figure 3(a).

J35 combustor. - The combustion efficiency values obtained with Jet Mix fuel in this combustor are better than those obtained with JP-3 fuel at 90-percent simulated rated rotor speed; however, the order is reversed at the low simulated rotor-speed condition. The maximum difference in combustion efficiency at either speed was about 4 percent (fig. 2(b)). The altitude operational limit curves followed a similar pattern, with JP-3 fuel providing limits 12,000 feet higher than Jet Mix fuel at 40-percent simulated rotor speed, as shown in figure 3(b). As simulated rotor speed increased, the difference decreased; at 65-percent normal rated rotor speed, the altitude operational limits of the two fuels are identical.

J47 combustor. - The combustion efficiency data obtained with this combustor indicate the same trends observed in the J35 combustor; that is, at the low simulated rotor-speed condition (fig. 2(c)), the JP-3 fuel provides higher efficiency values over most of the altitude range investigated, whereas at the high simulated rotor-speed condition the order is reversed. The maximum difference in combustion efficiency was greater with this combustor, being approximately 8 percent at the low simulated rotor-speed condition. The altitude limit curve obtained with each fuel is identical at each end of the range of rotor speeds investigated (fig. 3(c)), but elsewhere the limits observed with Jet Mix fuel were as much as 7000 feet lower.

<u>Annular combustor</u>. - The Jet Mix fuel gave higher efficiencies in the annular combustor at altitudes above 30,000 feet and the low simulated rotor-speed condition, with a maximum difference of 6 percent at 40,000 feet, as shown in figure 2(d). At the high simulated rotor-speed condition, the JP-3 fuel gave higher combustion efficiencies over the altitude range investigated, varying from 1 percent at 30,000 feet to 9 percent at 50,000 feet. No differences in altitude operational limits of the two fuels were observed in this combustor.

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The three tubular combustors used in this investigation had, in general, higher altitude operational limits with JP-3 fuel than with Jet Mix fuel. The difference in combustion efficiency values obtained with each fuel depended on the specific altitude and rotor-speed condition simulated; generally, the JP-3 fuel provided efficiencies 3 to 5 percent higher than Jet Mix fuel at the lowest simulated rotor speeds and altitudes investigated, whereas the Jet Mix fuel provided efficiencies 2 to 3 percent higher than JP-3 fuel at the higher simulated rotor speeds and altitudes investigated. The trends in combustion efficiency data for the NACA annular combustor are opposite to those obtained with the tubular combustors and no difference in altitude limits was observed with the two fuels in the annular combustor.

Carbon-Deposition Characteristics

The amounts of carbon formed by the two fuels in 4 hours of operation of the J33 combustor are plotted in figure 4 on a previously developed correlation curve given in reference 3. The unleaded Jet Mix fuel formed twice as much carbon (7 g) as did the particular JP-3 fuel used in this investigation. Single-combustor and full-scale engine carbon-deposition values are analyzed and plotted on this correlation in reference 2, showing that a fuel having an NACA K factor of 310 or less will not give carbon-deposition problems in current turbojet engines that have been designed for use with JP-3 type fuels. Figure 4 shows that Jet Mix fuel has a K factor of approximately 305 and therefore will operate satisfactorily without forming excessive carbon deposits. This fuel quality estimate does indicate, however, that Jet Mix fuel is marginal with respect to carbon deposition and that other Jet Mix fuels with a larger percentage of aromatic constituents can be expected to yield more carbon.

The tetraethyl lead additive that would be present when the fuel is blended from leaded MIL-F-5572 fuel aboard carriers could result in increased deposits. An investigation of carbon deposition in a J33 single combustor using fuels containing metallic organic additives, including tetraethyl lead, is described in reference 8. The results indicated that the concentration of tetraethyl lead that would be present in Jet Mix fuels used in carrier-based aircraft would probably decrease carbon formation but the added lead oxide deposition would probably increase the total weight of deposits.

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CONCLUDING REMARKS

The performance investigation with both tubular and annular type combustors indicates that Jet Mix fuel can be used satisfactorily over the normal operating range in a number of representative current turbojet engines. A small (3 to 5 percent) gain or loss in combustion efficiency from that provided by the JP-3 fuel used in this investigation may result but the variation in performance may depend on the particular altitude and rotor speed condition at which the engine is operated if the Jet Mix fuel is used. In the J33 combustor, the altitude limits were lowered approximately 8000 feet with Jet Mix fuel throughout the simulated rotor speed and altitude range investigated. For the other tubular combustors, the Jet Mix fuel gave lower altitude limits than the JP-3 fuel only in the low simulated rotor-speed range. No difference in altitude-operational limits between fuels was found with the experimental NACA annular combustor. No excessive carbon deposits were encountered with unleaded Jet Mix fuel, although this fuel may be marginal in this respect.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
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TABLE I - FUEL ANALYSES

Fuel properties	MIL-F-5624A (JP-3) (NACA fuel 51-186)	Navy Jet Mix (NACA fuel 51-201)	MIL-F-7914, grade JP-5 (NACA fuel 51-170)	Unleaded MIL-F-5572 (NACA fuel 49-167)
A.S.T.M. distillation D86-46, (°F)				
Initial boiling point	118	142	357	120
Percentage evaporated				
5	158	192	371	136
10	177	230	375	161
20	205	289	385	182
30	234	338	393	196
40	263	371	402	205
50	294	394	411	210
60	328	407	421	217
70	359	420	433	221
80	397	436	448	227
90	433	457	464	239
Final boiling point	492	499	502	309
Residue (percent)	1.3	1.1	0.7	1.0
Loss (percent)	1.1	1.0	.2	2.0
Freezing point (°F)	-62	-60	-----	-----
Aromatics Silica gel (percent by volume)	9.0	13.4	-----	-----
Olefins Silica gel (percent by weight)	.5	.5	-----	-----
Gravity				
°API	55.8	48.7	43.7	66.3
Specific	.756	.785	.808	.715
Reid vapor pressure (lb/sq in.)	6.5	2.0	.2	5.0
Hydrogen-carbon ratio	.171	.164	-------	------
Heat of combustion (Btu/lb)	18,740	18,670	-------	------
Gum, (mg/100 ml)				
Air jet residue	1	2	-------	------
Accelerated	5	4	-------	------
Aniline point (°F)	137.1	142.2	145.8	------
Bromine number	.7	.5	-------	------
Flash point (°F)	---------	----------	142	------

TABLE II - PERFORMANCE DATA FROM SEVERAL COMBUSTORS OPERATING WITH MIL-F-5624A (JP-3) AND JET MIX FUELS AT MACH NUMBER 0.60

(a) J33 combustor

Simulated altitude (ft)	Percent rated engine speed	Combustor inlet total pressure (in. Hg)	Combustor inlet temperature ($^{\circ}$R)	Air flow (lb/sec)	Combustor reference velocity (ft/sec)	Fuel flow (lb/hr)	Fuel-air ratio	Mean combustor outlet temperature ($^{\circ}$R)	Mean temperature rise through combustor ($^{\circ}$F)	Combustion efficiency	Total-pressure drop through combustor (in. Hg)	Fuel nozzle differential pressure (in. Hg)
MIL-F-5624A (JP-3) fuel												
20,000	60	33.2	605	2.13	109	50.7	0.00661	995	390	0.781	2.9	6
	70	41.3	654	2.68	119	64.4	.00667	1090	438	.873	3.8	12
	80	51.5	709	3.13	121	83.6	.00742	1245	536	.879	4.6	57
	90	65.5	732	3.43	108	129.4	.0105	1515	783	1.03	4.9	76
30,000	60	22.6	570	1.52	108	40.5	.00740	930	360	.642	2.2	--
	70	28.3	616	1.90	116	49.7	.00727	1045	426	.785	2.9	7
	80	35.9	670	2.21	116	64.5	.00811	1225	555	.925	3.3	13
	80	35.9	669	2.20	115	65.5	.00827	1230	561	.918	3.2	13
	90	45.2	724	2.44	110	95.4	.0108	1510	786	1.01	3.8	39
	100	55.3	778	2.80	103	159.8	.0149	1845	1067	1.03	3.8	92
40,000	60	14.5	548	1.02	109	34.6	.00946	908	357	.498	1.5	--
	70	18.5	595	1.24	112	37.6	.00848	1010	414	.652	1.2	--
	80	23.5	647	1.44	112	47.3	.00916	1210	563	.831	2.2	8
	90	28.6	700	1.59	106	67.1	.0118	1500	800	.843	2.3	17
	100	36.3	753	1.71	99.9	97.4	.0158	1820	1067	.971	2.5	42
50,000	60	9.0	550	.648	110	←Required temperature rise unattainable→						--
	60	9.0	550	.642	110	32.0	.0138	910	360	.348	1.2	--
	70	11.5	598	.787	115	51.4	.0111	1015	419	.505	1.2	--
	80	14.5	648	.905	114	35.0	.0107	1210	562	.713	1.5	--
	90	18.2	702	.986	107	45.1	.0127	1500	798	.876	1.7	--
	100	22.5	754	1.010	95.2	62.0	.0171	1815	1061	.895	1.5	--
60,000	70	7.2	596	.485	113	43.6	.0250	1010	414	.229	.9	--
	80	9.1	648	.560	112	40.0	.0199	1215	567	.396	.9	--
	90	11.4	699	.609	105	39.1	.0178	1500	801	.636	1.0	--
	100	14.0	753	.654	99.0	44.1	.0187	1820	1067	.828	1.0	--
Jet Mix fuel												
20,000	60	33.1	606	2.13	109	52.0	0.00680	995	389	0.761	2.9	7
	70	41.3	655	2.67	119	63.0	.00655	1090	435	.690	3.7	12
	80	51.6	710	3.13	121	85.5	.00759	1245	535	.859	5.0	57
	90	65.0	727	3.52	111	138.1	.0109	1510	783	1.00	5.0	76
30,000	60	22.6	569	1.54	109	42.6	.00768	935	366	.632	2.2	6
	70	28.3	618	1.89	116	50.8	.00747	1040	424	.758	2.9	7
	80	35.9	670	2.21	116	66.5	.00836	1250	560	.910	3.2	13
	80	35.8	670	2.20	115	66.0	.00833	1225	555	.905	3.3	13
	90	45.2	724	2.44	110	97.2	.0111	1505	781	.982	3.5	40
	100	55.6	778	3.81	103	144.2	.0153	1845	1067	1.01	3.8	98
40,000	60	14.4	549	1.04	112	36.9	.00986	906	356	.479	1.6	--
	60	14.4	547	1.02	109	36.7	.0100	905	358	.475	1.5	--
	70	18.5	596	1.24	112	38.9	.00870	1010	414	.636	1.8	--
	80	23.4	647	1.43	111	49.1	.00953	1210	563	.802	2.2	8
	90	29.6	701	1.58	105	67.9	.0120	1500	789	.930	2.3	16
	100	36.3	752	1.70	99.0	98.5	.0161	1820	1068	.958	2.5	40
50,000	60	9.0	549	.846	110	----	←Required temperature rise unattainable→					
	70	11.5	596	.793	116	34.1	.0120	1010	414	.464	1.3	--
	80	14.5	648	.900	113	36.4	.0112	1210	562	.685	1.5	--
	90	18.2	702	.980	106	47.0	.0133	1500	798	.841	1.6	--
	100	22.5	753	.985	92.8	65.0	.0178	1820	1067	.870	1.6	15
60,000	90	11.4	700	.612	106	33.6	.0153	1500	800	.736	1.0	--
	100	14.0	753	.652	98.8	44.4	.0189	1825	1072	.825	1.0	--

TABLE II - PERFORMANCE DATA FROM SEVERAL COMBUSTORS OPERATING WITH MIL-F-5624A (JP-3) AND JET MIX FUELS AT MACH NUMBER 0.60 - Continued

(b) J35 combustor

Simulated altitude (ft)	Simulated engine speed (rpm)	Combustor inlet static pressure (in. Hg)	Combustor inlet temperature (°R)	Air flow (lb/sec)	Combustor reference velocity (ft/sec)	Fuel flow (lb/hr)	Fuel air ratio	Mean combustor outlet temperature (°R)	Mean temperature rise through combustor (°F)	Combustion efficiency	Total pressure drop through combustor (in. Hg)	Fuel nozzle differential pressure (in. Hg)
MIL-F-5624A (JP-3) fuel												
20,000	3000	23	530	1.4	50.6	18.5	0.00367	740	210	0.740	--	--
	4000	27	570	2.3	76.1	28.5	.00344	810	240	.907	--	--
	5000	35	610	3.2	87.4	52	.00452	925	318	.914	--	51
	6000	47	675	4.3	96.8	100	.00646	1140	465	.965	--	57
30,000	3000	15	490	1.0	51.2	19	.00528	690	200	.490	--	--
	4000	19	525	1.6	69.3	23.5	.00408	760	235	.748	--	--
	5000	24	575	2.3	86.4	38.5	.00465	885	310	.870	--	33
	6000	33	635	3.0	90.5	77	.00713	1130	495	.928	--	63
	7000	44	700	5.6	89.7	153	.0118	1510	810	.954	--	77
40,000	3000	10	490	0.70	56.8	7.0	.00278	Lean limit blow-out				
	4000	12	505	1.1	72.6	20	.00505	740	235	.602	--	--
	5000	15	555	1.5	87.0	28.5	.00528	860	305	.756	--	18
	6000	21	615	2.0	91.8	55	.00764	1120	505	.882	--	58
	7000	28	680	2.3	87.4	102	.0123	1510	830	.938	--	76
	8000	34	740	2.6	88.6	164	.0175	1900	1160	.960	--	87
50,000	4000	8	505	0.70	89.3	15.5	.00615	Lean limit blow-out				
	5000	10	550	0.90	77.6	23	.00710	860	310	.573	--	--
	6000	14	615	1.2	82.6	42	.00972	1120	505	.697	--	58
	7000	18	680	1.4	82.9	72	.0143	1510	830	.811	--	78
	8000	21	740	1.6	88.3	113	.0196	1900	1160	.862	--	85
60,000	5000	7	550	0.70	86.2	21	.00833	Lean limit blow-out				
	6000	9	615	0.90	86.4	51	.0157	1120	505	.438	--	61
	7000	12	680	1.0	88.8	64	.0178	1510	830	.657	--	76
	8000	15	740	1.1	88.0	86	.0217	1900	1160	.784	--	83
Jet Mix fuel												
20,000	3000	23	530	1.4	50.6	20.0	0.00397	740	210	0.888	--	--
	4000	27	570	2.3	76.1	30.5	.00368	810	240	.850	--	26
	5000	35	610	3.2	87.4	53	.00460	925	315	.902	--	51
	6000	47	675	4.3	96.8	104	.00672	1140	465	.932	--	64
30,000	3000	15	490	1.0	51.2	17.0	.00472	Lean limit blow-out				
	4000	19	525	1.6	69.3	25.0	.00434	760	235	.706	--	--
	5000	24	575	2.3	86.4	40.0	.00483	885	310	.843	--	40
	6000	33	635	3.0	90.5	82	.00759	1130	495	.877	--	65
	7000	44	695	3.6	89.1	157	.0121	1510	815	.940	--	77
40,000	4000	12	505	1.1	72.6	28.5	.00720	740	235	.426	--	--
	5000	15	580	1.5	87.8	29.5	.00546	860	300	.722	--	24
	6000	21	615	2.0	91.8	60	.00833	1120	505	.814	--	65
	7000	28	680	2.3	87.4	106	.0128	1510	830	.906	--	78
	8000	34	740	2.6	88.6	172	.0184	1900	1160	.918	--	89
50,000	4000	8	500	0.71	69.6	24.5	.00958	Lean limit blow-out				
	5000	10	560	0.90	79.0	21.5	.00664	860	300	.596	--	--
	6000	14	615	1.2	82.6	47.0	.0109	1120	505	.626	--	52
	7000	18	680	1.4	82.9	69	.0137	1510	830	.847	--	74
	8000	21	740	1.6	88.3	110	.0191	1900	1160	.886	--	85
60,000	5000	7	560	0.70	87.8	21.0	.00833	Lean limit blow-out				
	6000	9	615	0.90	96.4	56	.0173	1120	505	.400	--	69
	7000	12	680	1.0	88.8	64	.0178	1510	830	.660	--	76
	8000	15	740	1.1	88.0	85	.0215	1900	1160	.792	--	81

TABLE II - PERFORMANCE DATA FROM SEVERAL COMBUSTORS OPERATING WITH MIL-F-5624A (JP-3) AND JET MIX FUELS AT MACH NUMBER 0.60 - Continued

(c) J47 combustor

Simulated altitude (ft)	Simulated engine speed (rpm)	Combustor inlet total pressure (in. Hg)	Combustor inlet temperature (°R)	Air flow (lb/sec)	Combustor reference velocity (ft/sec)	Fuel flow (lb/hr)	Fuel air ratio	Mean combustor outlet temperature (°R)	Mean temperature rise through combustor (°F)	Combustion efficiency	Total pressure drop through combustor (in. Hg)	Fuel nozzle differential pressure (in. Hg)
MIL-F-5624A (JP-3) fuel												
20,000	3000	20.7	528	2.21	88.0	22.9	0.00288	650	122	.546	--	---
	4000	28.0	584	3.24	106	30.8	.00264	745	161	.790	--	7
	5000	42.7	653	4.46	107	48.4	.00301	865	212	.921	--	21
30,000	4000	19.3	560	2.27	102	25.7	.00315	705	165	.637	--	---
	5000	30.2	618	3.19	103	39.6	.00345	840	222	.841	--	13
	6000	43.4	694	4.22	106	85.9	.00565	1105	411	.972	--	78
40,000	4000	12.7	532	1.51	99.2	18.4	.00338	690	158	.604	--	---
	5000	19.6	598	2.09	100	30.0	.00398	815	217	.711	--	---
	6000	28.0	670	2.75	103	61.3	.00619	1090	420	.906	--	39
	7000	35.5	754	3.07	102	127	.0116	1550	796	.971	--	158
	7500	38.7	784	3.11	98.9	168	.0151	1800	1016	.970	--	178
50,000	4000	7.8	530	0.981	105	15.5	.00458	Lean limit blow-out				
	5000	12.2	588	1.30	98.3	23.6	.00602	825	237	.617	--	---
	6000	17.7	674	1.72	103	42.6	.00686	1085	411	.802	--	18
	7000	22.2	760	1.82	103	84.5	.0125	1535	798	.912	--	82
	7900	25.3	828	1.81	98.2	150	.0189	2010	1181	.922	--	161
60,000	4000	5.8	555	0.687	103	17.0	.00887	Lean limit blow-out				
	5000	8.8	595	0.938	99.6	23.5	.00696	810	215	.408	--	---
	6000	12.1	675	1.24	108	38.5	.00861	1085	410	.640	--	---
	7000	15.3	751	1.37	106	65.0	.0128	1550	799	.879	--	45
	7900	17.6	828	1.38	102	98.5	.0198	2010	1182	.883	--	118
Jet Mix fuel												
20,000	3000	20.8	530	2.19	87.7	26.3	0.00333	655	125	0.487	--	---
	4000	28.0	583	3.24	106	33.2	.00285	750	167	.762	--	7
	5000	42.7	653	4.50	108	49.5	.00306	860	207	.890	--	20
30,000	4000	19.3	550	2.26	101	29.5	.00362	705	155	.557	--	---
	5000	30.2	618	3.18	102	39.5	.00344	830	212	.807	--	13
	6000	43.4	691	4.24	106	88.6	.00581	1110	419	.969	--	86
40,000	4000	12.7	550	1.50	102	28.0	.00517	Lean limit blow-out				
	5000	19.6	598	2.09	101	31.8	.00423	810	212	.657	--	---
	6000	28.0	672	2.75	104	62.4	.00630	1090	418	.890	--	37
	7000	35.5	756	3.06	102	127	.00115	1550	795	.970	--	150
	7500	38.7	793	3.07	99.0	166	.0150	1805	1012	.977	--	171
50,000	4000	7.8	540	0.947	99.9	20.4	.00599	Lean limit blow-out				
	5000	12.0	602	1.30	103	21.5	.00458	790	188	.538	--	---
	6000	17.7	674	1.75	104	44.9	.00720	1095	421	.787	--	17
	7000	22.2	757	1.92	103	82.0	.0119	1545	788	.933	--	74
	7900	25.3	830	1.91	98.1	130	.0189	2020	1190	.933	--	155
60,000	5000	8.8	597	0.094	100	19.2	.00587	830	233	.541	--	---
	6000	12.1	671	1.24	108	35.2	.00789	1065	414	.707	--	---
	7000	15.3	750	1.37	105	63.5	.0129	1555	805	.882	--	40
	7900	17.6	827	1.38	102	98.2	.0197	2010	1183	.890	--	105

TABLE II - PERFORMANCE DATA FROM SEVERAL COMBUSTORS OPERATING WITH MIL-F-5624A (JP-3) AND JET MIX FUELS AT MACH NUMBER 0.60 - Concluded

(d) NACA annular combustor

Simulated altitude (ft)	Simulated engine speed (rpm)	Combustor inlet total pressure (in. Hg)	Combustor inlet temperature (°R)	Air flow (lb/sec)	Combustor reference velocity (ft/sec)	Fuel Flow (lb/hr)	Fuel air ratio	Mean combustor outlet temperature (°R)	Mean temperature rise through combustor (°F)	Combustion Efficiency	Total pressure drop through combustor (in. Hg)	Manifold differential pressure (in. Hg)
MIL-F-5624A (JP-3) fuel												
30,000	7,800	19.7	540	3.03	85.8	112	0.0103	1155	615	0.803	---	---
	8,700	23.5	560	3.67	90.5	132	.0100	1195	635	.855	---	---
	9,600	28.2	604	4.35	96.4	169	.0108	1303	699	.885	---	---
40,000	7,800	12.5	560	1.91	88.5	102	.0148	1260	700	.660	---	---
	8,700	15.9	540	2.31	81.0	119	.0144	1223	683	.659	---	---
	9,600	18.1	579	2.71	89.7	121	.0124	1316	737	.812	---	---
	10,400	21.3	612	3.05	90.6	157	.0143	1485	873	.856	---	---
	11,300	24.7	653	3.32	90.7	204	.0171	1762	1109	.930	---	---
50,000	10,400	12.8	602	1.65	80.3	167	.0283	1720	1118	.599	---	---
	11,300	15.1	663	1.83	83.0	167	.0254	1997	1334	.789	---	---
55,000	11,300	11.8	646	1.27	72.0	135	.0296	2100	1454	.755	---	---
Jet Mix fuel												
30,000	7,800	19.7	544	3.04	86.9	113	0.0103	1156	612	0.800	---	---
	8,700	23.5	544	3.68	88.2	133	.0100	1184	640	.859	---	---
	9,600	28.2	600	4.41	96.2	168	.0106	1289	689	.883	---	---
40,000	6,100	8.30	480	1.21	72.4	←Required temperature rise unattainable→						
	7,000	10.1	500	1.50	76.7	←Required temperature rise unattainable→						
	7,800	12.5	544	1.91	86.0	89.0	.0130	1211	667	.709	---	---
	8,700	14.9	544	2.32	87.6	102	.0122	1234	690	.780	---	---
	9,600	18.1	582	2.71	90.2	114	.0117	1287	705	.835	---	---
	10,400	21.0	617	3.06	83.0	168	.0153	1493	876	.808	---	---
	11,300	24.5	648	3.32	90.8	210	.0176	1759	1111	.912	---	---
50,000	10,400	12.8	611	1.65	81.5	156	.0263	1725	1114	.634	---	---
	11,300	14.9	655	1.81	82.3	194	.0297	1989	1334	.691	---	---
55,000	10,400	9.80	605	1.10	70.3	←Required temperature rise unattainable→						
	11,300	11.8	641	1.26	70.8	171	.0377	2140	1499	.666	---	---
60,000	11,300	9.20	657	.805	59.6	←Required temperature rise unattainable→						

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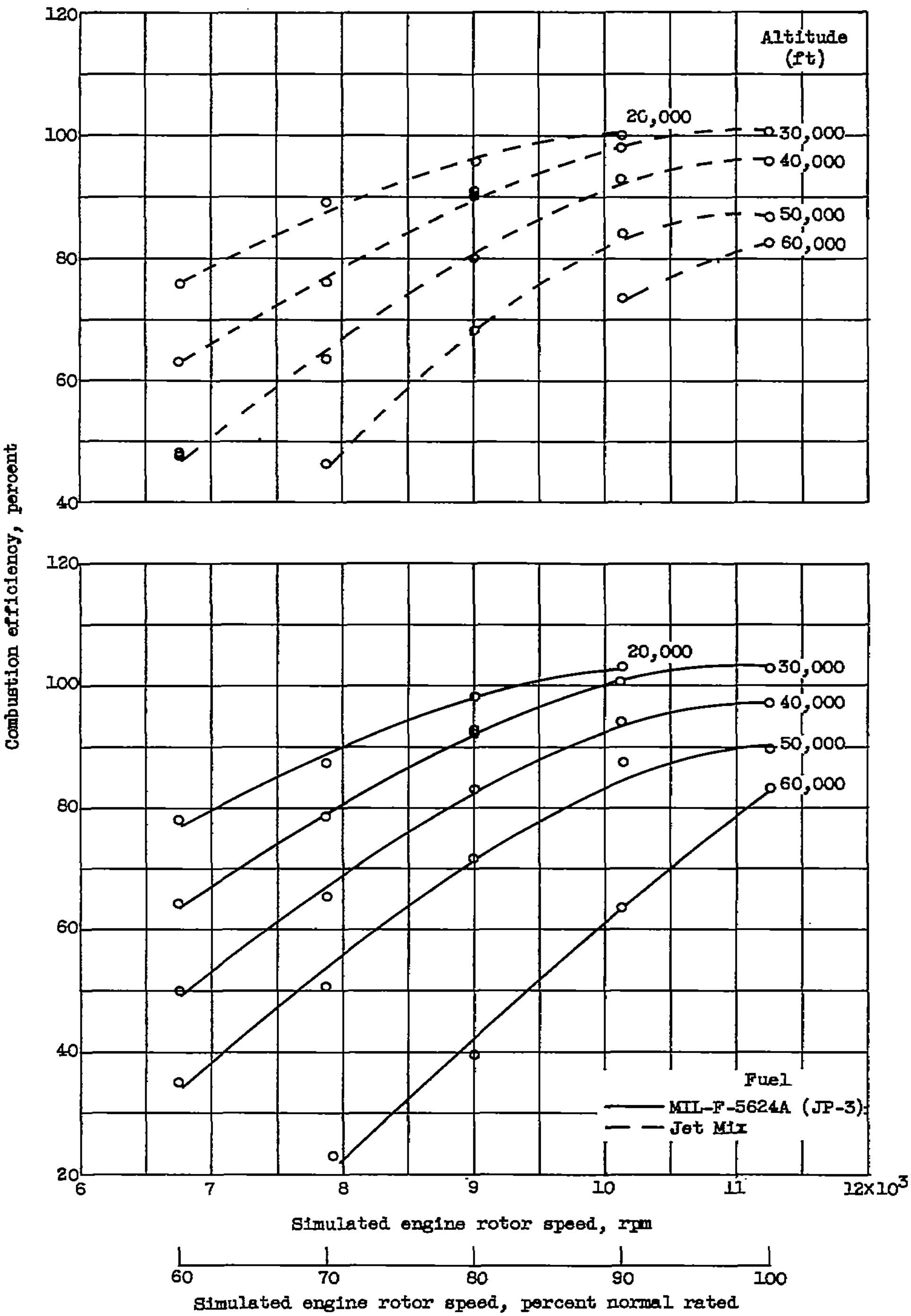

(a) J33 combustor.

Figure 1. - Variation of combustion efficiency with simulated engine rotor speed over altitude range from 20,000 to 60,000 feet for several combustors. Fuels, Jet Mix and MIL-F-5624A (JP-3); Mach number, 0.6.

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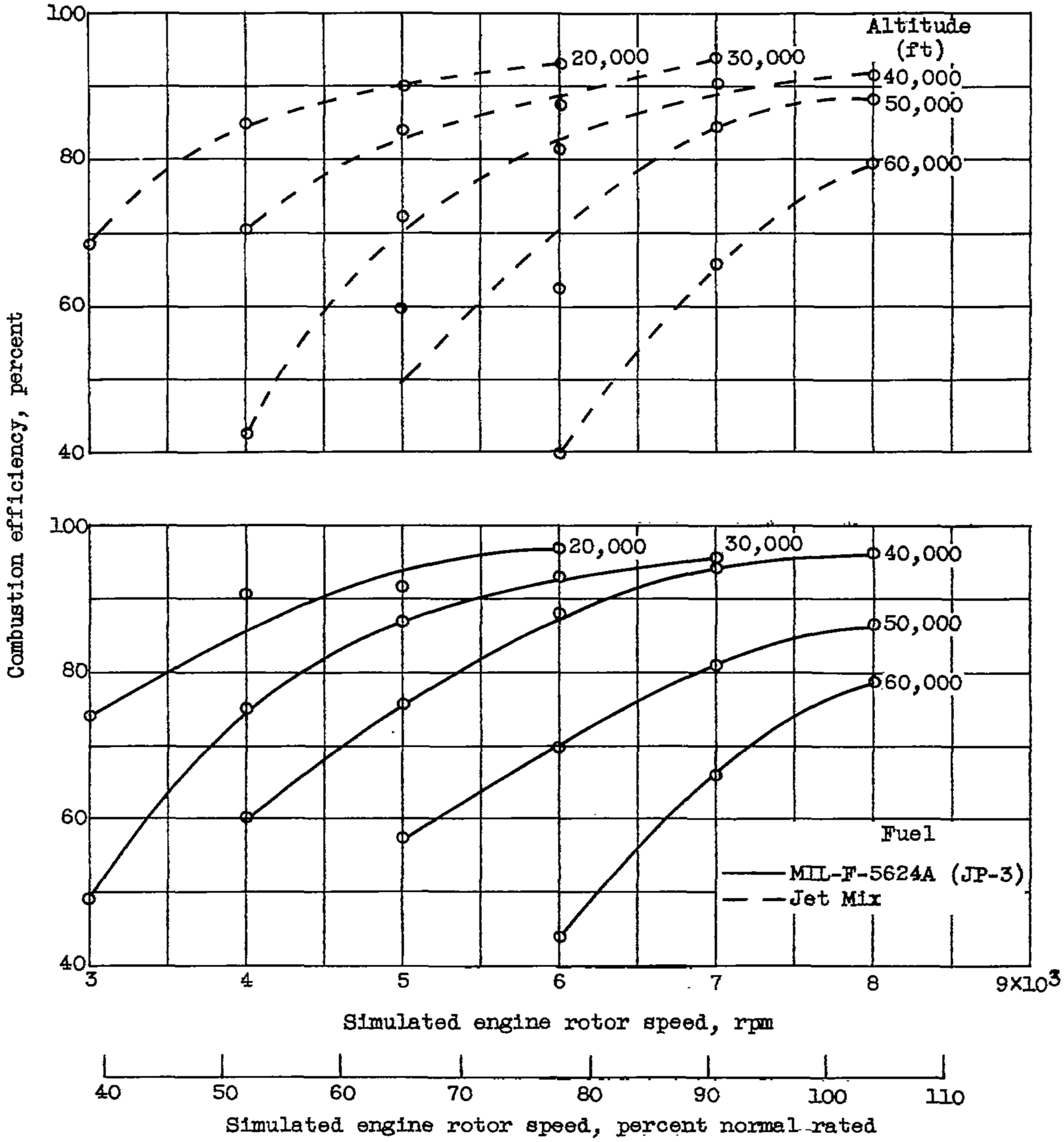

(b) J35 combustor.

Figure 1. - Continued. Variation of combustion efficiency with simulated engine rotor speed over altitude range from 20,000 to 60,000 feet for several combustors. Fuels, Jet Mix and MIL-F-5624A (JP-3); Mach number, 0.6.

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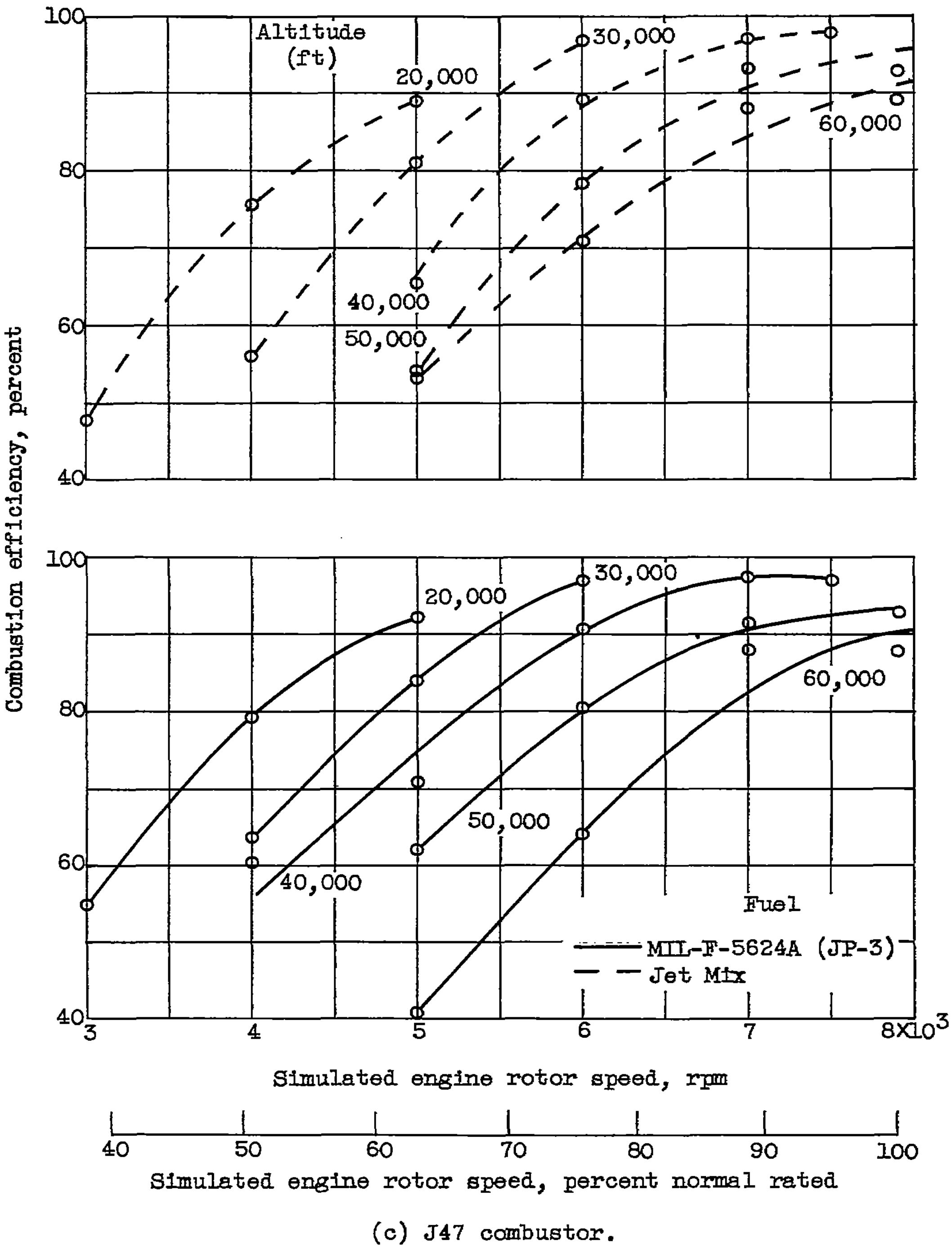

(c) J47 combustor.

Figure 1. - Continued. Variation of combustion efficiency with simulated engine rotor speed over altitude range from 20,000 to 60,000 feet for several combustors. Fuels, Jet Mix and MIL-F-5624A (JP-3); Mach number, 0.6.

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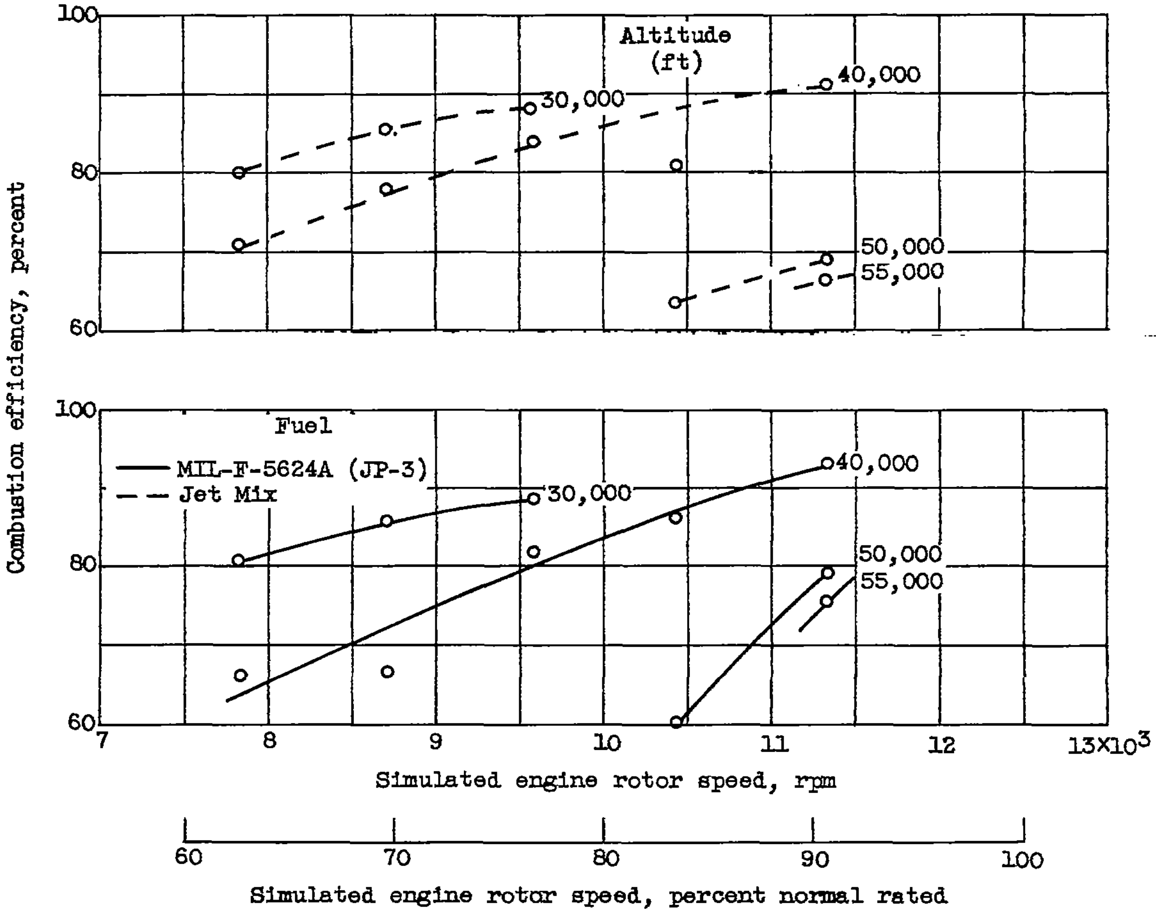

(d) NACA annular combustor.

Figure 1. - Concluded. Variation of combustion efficiency with simulated engine rotor speed over altitude range from 20,000 to 60,000 feet for several combustors. Fuels, Jet Mix and MIL-F-5624A (JP-3); Mach number, 0.6.

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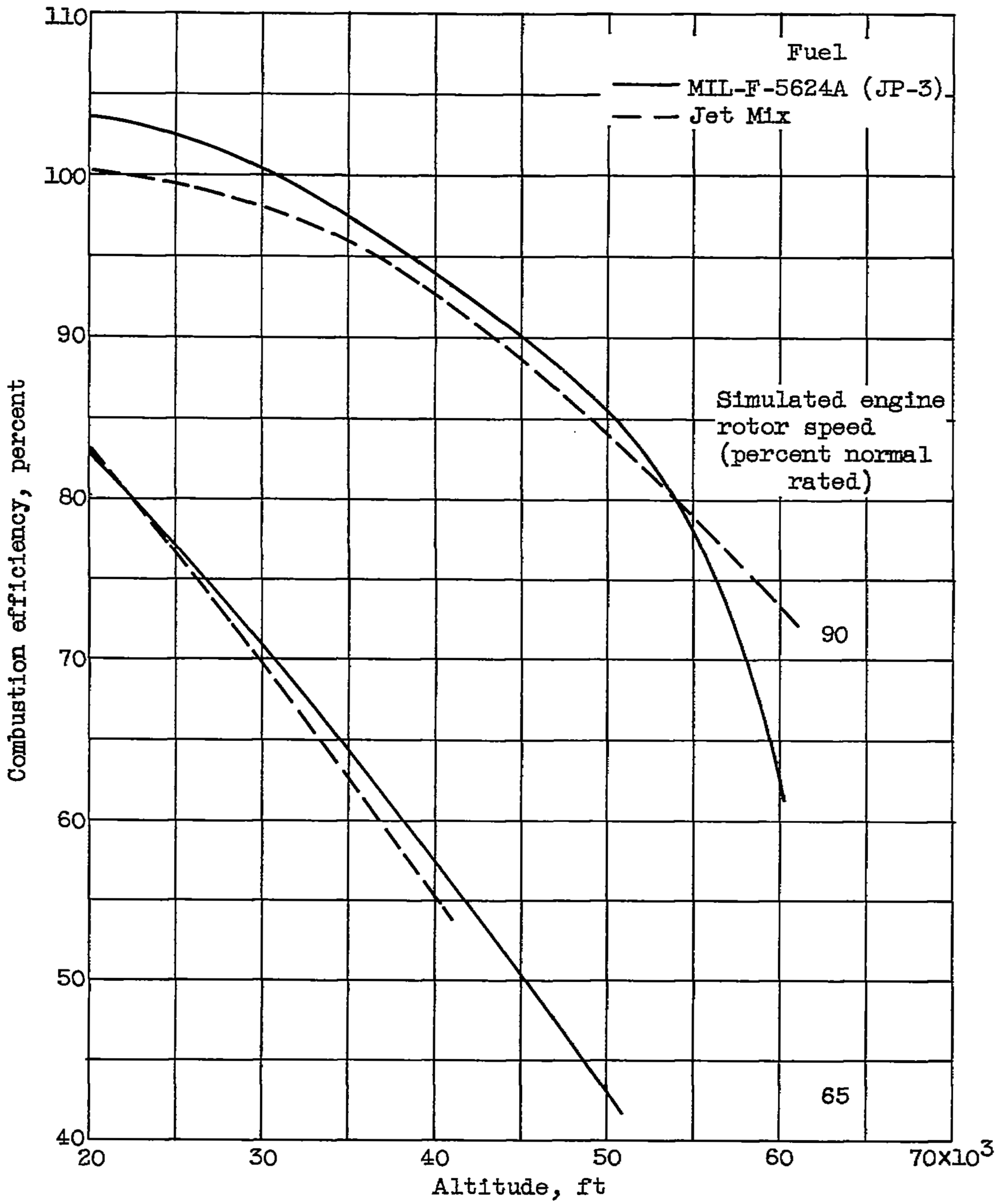
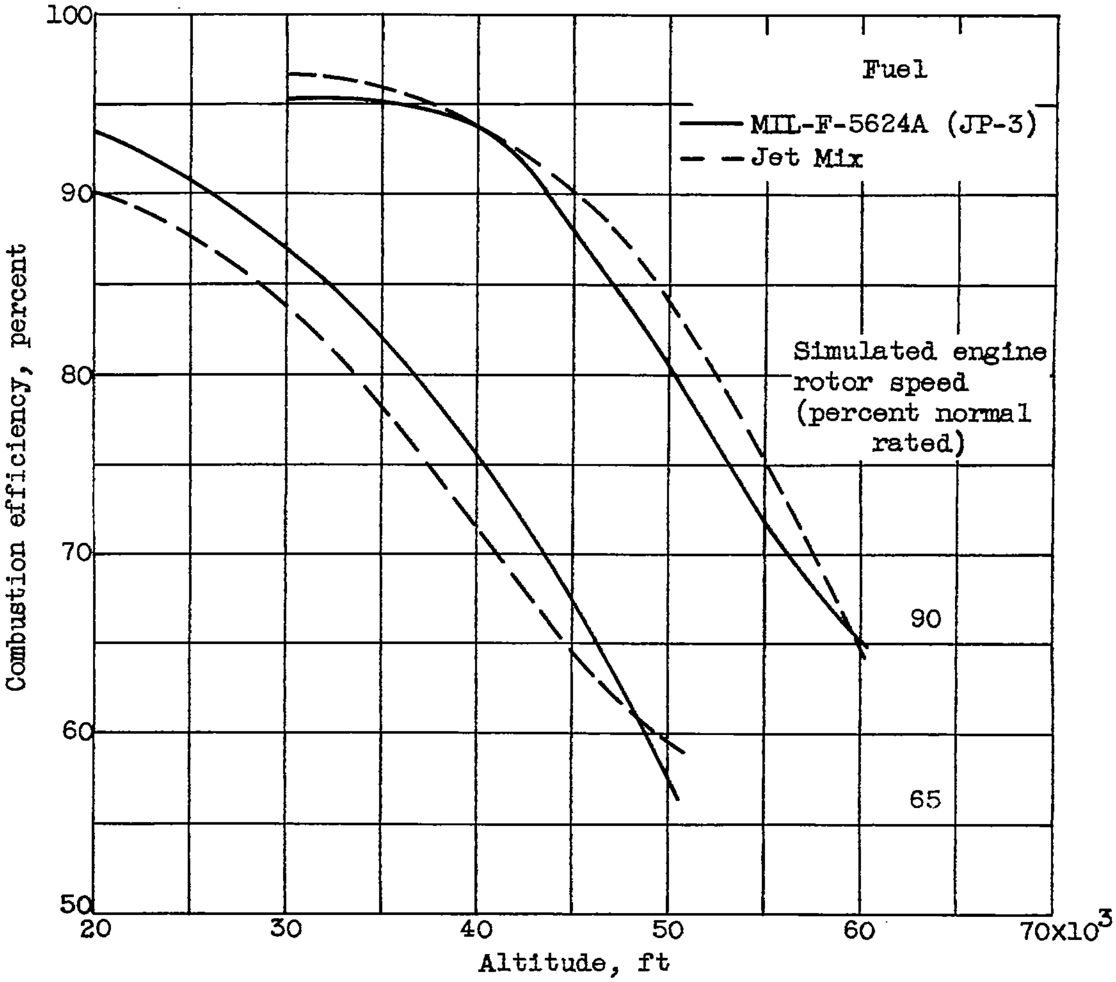


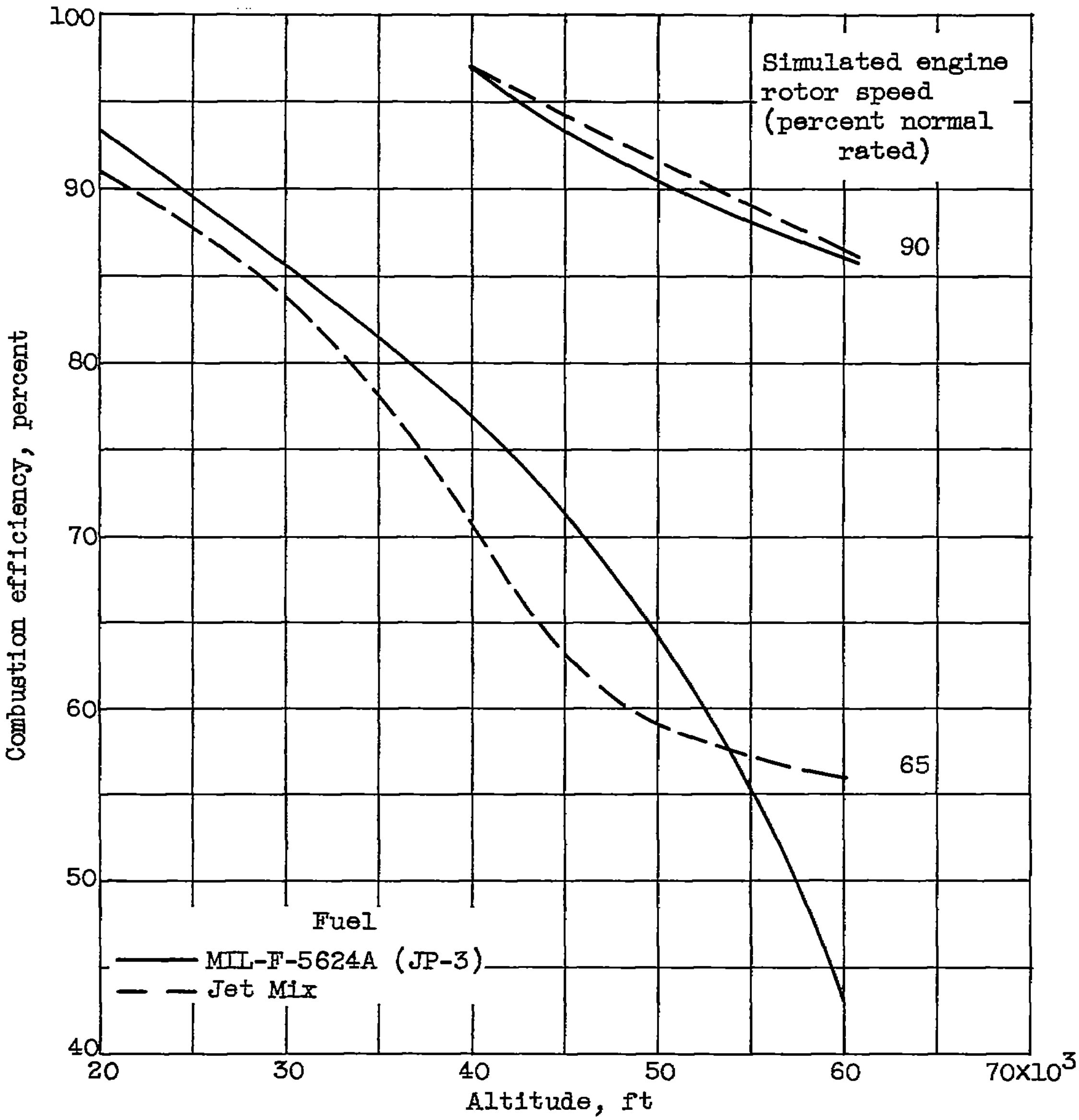
(a) J33 combustor.

Figure 2. - Effect of altitude on combustion efficiency obtained at two constant simulated rotor speeds for several combustors. Fuels, Jet Mix and MIL-F-5624A (JP-3); Mach number, 0.6.



(b) J35 combustor.

Figure 2. - Continued. Effect of altitude on combustion efficiency obtained at two constant simulated rotor speeds for several combustors. Fuels, Jet Mix and MIL-F-5624A (JP-3); Mach number, 0.6.



(c) J47 combustor.

Figure 2. - Continued. Effect of altitude on combustion efficiency obtained at two constant simulated rotor speeds for several combustors. Fuels, Jet Mix and MIL-F-5624A (JP-3); Mach number, 0.6.

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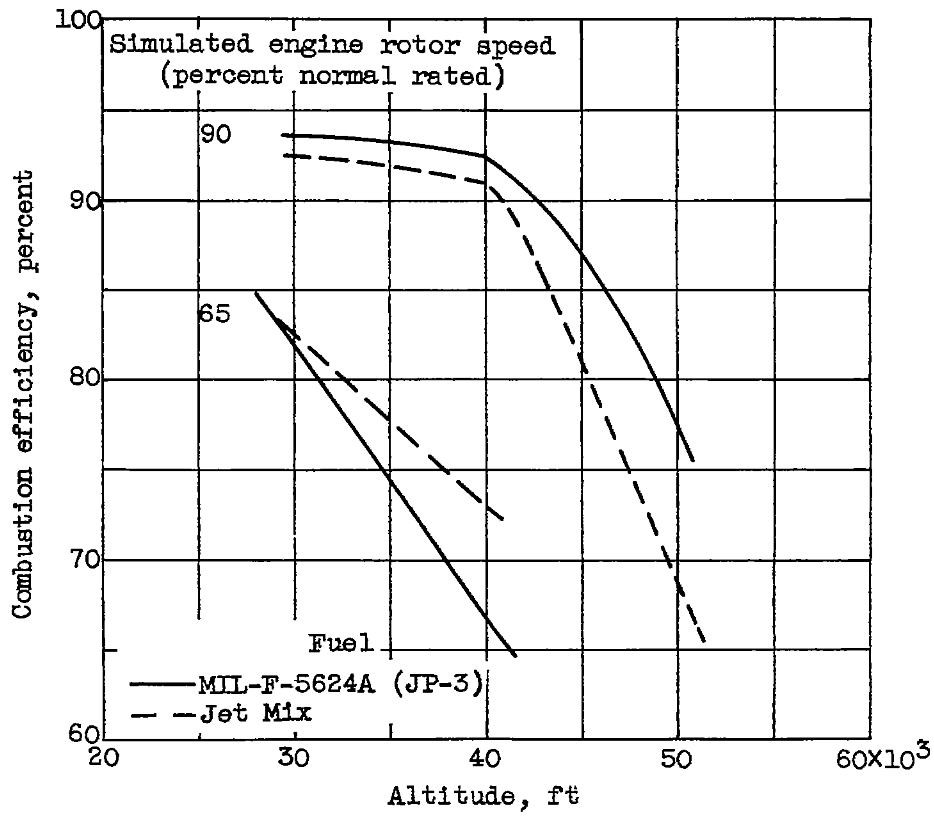

(d) NACA annular combustor.

Figure 2. - Concluded. Effect of altitude on combustion efficiency obtained at two constant simulated rotor speeds for several combustors. Fuels, Jet Mix and MIL-F-5624A (JP-3); Mach number, 0.6.

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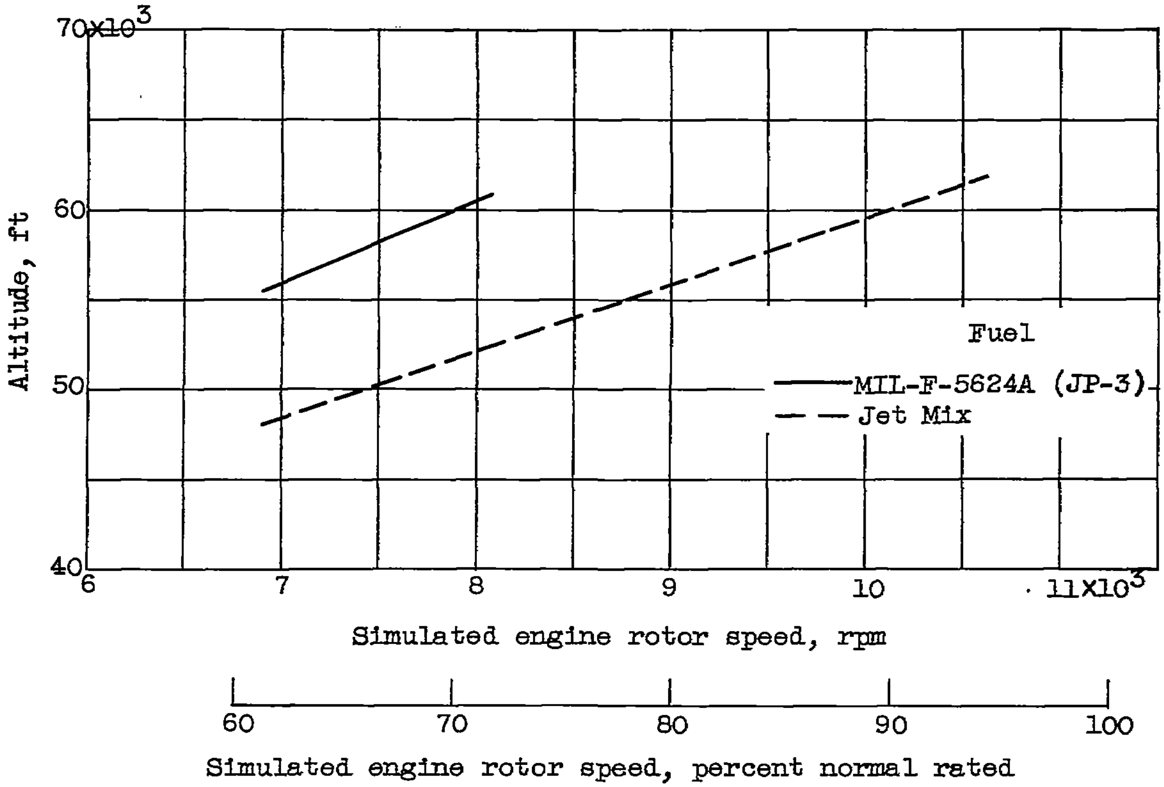
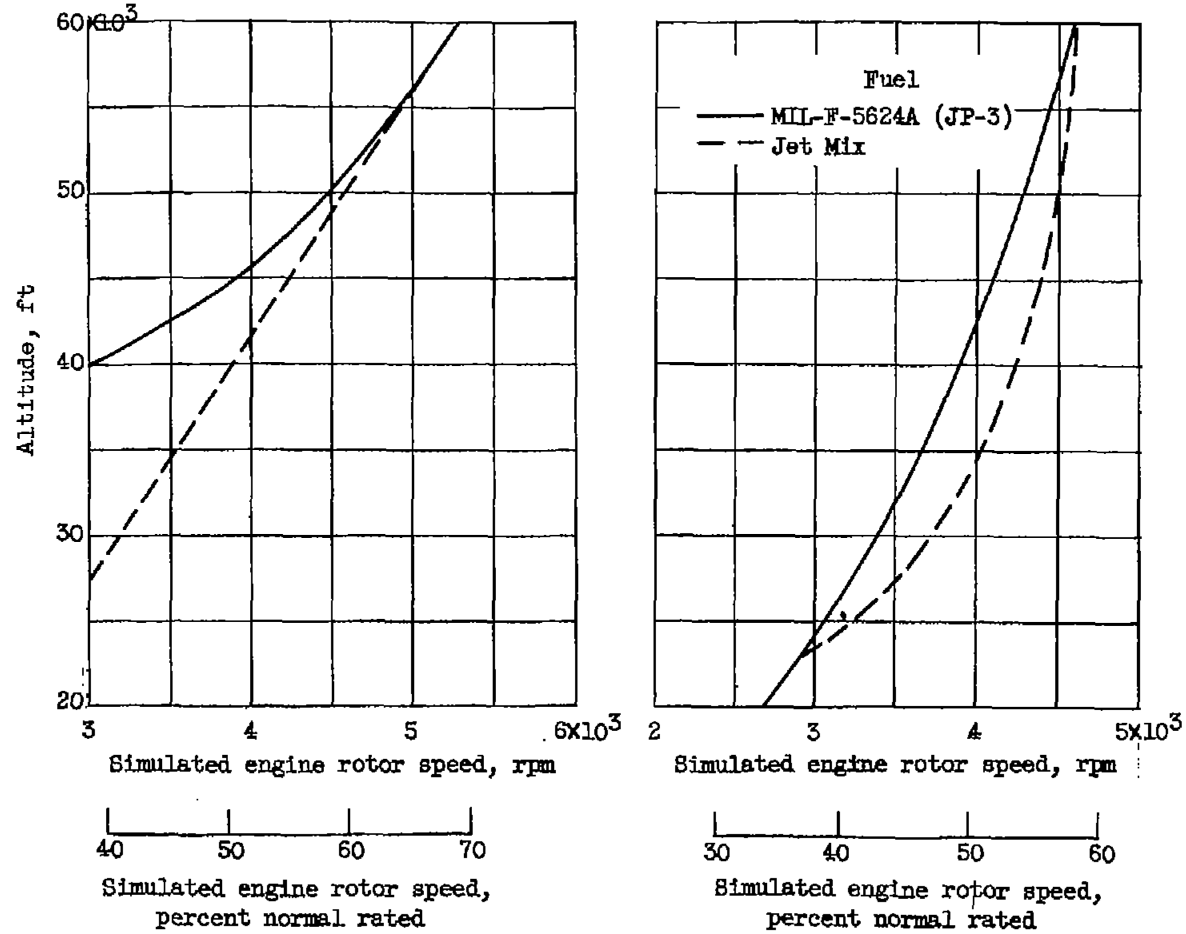


(a) J33 combustor.

Figure 3. - Comparison of altitude operational limits obtained with Jet Mix and MIL-F-5624A (JP-3) fuels for several combustors. Mach number, 0.6.



(b) J35 combustor.

(c) J47 combustor.

Figure 3. - Continued. Comparison of altitude operational limits obtained with Jet Mix and MIL-F-5624A (JP-3) fuels for several combustors. Mach number, 0.6.

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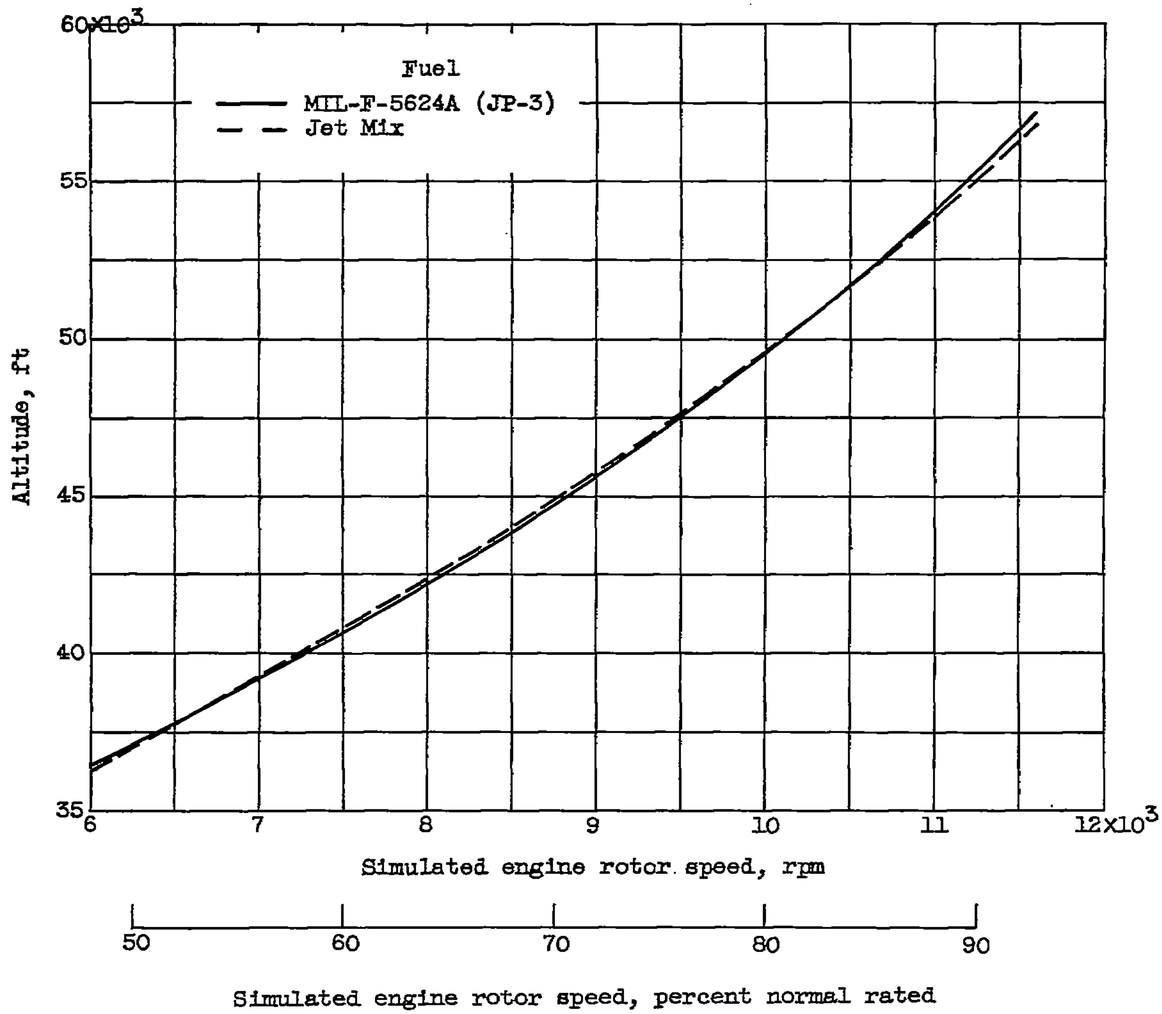

(d) NACA annular combustor.

Figure 3. - Concluded. Comparison of altitude operational limits obtained with Jet Mix and MIL-F-5624A (JP-3) fuels for several combustors. Mach number, 0.6.

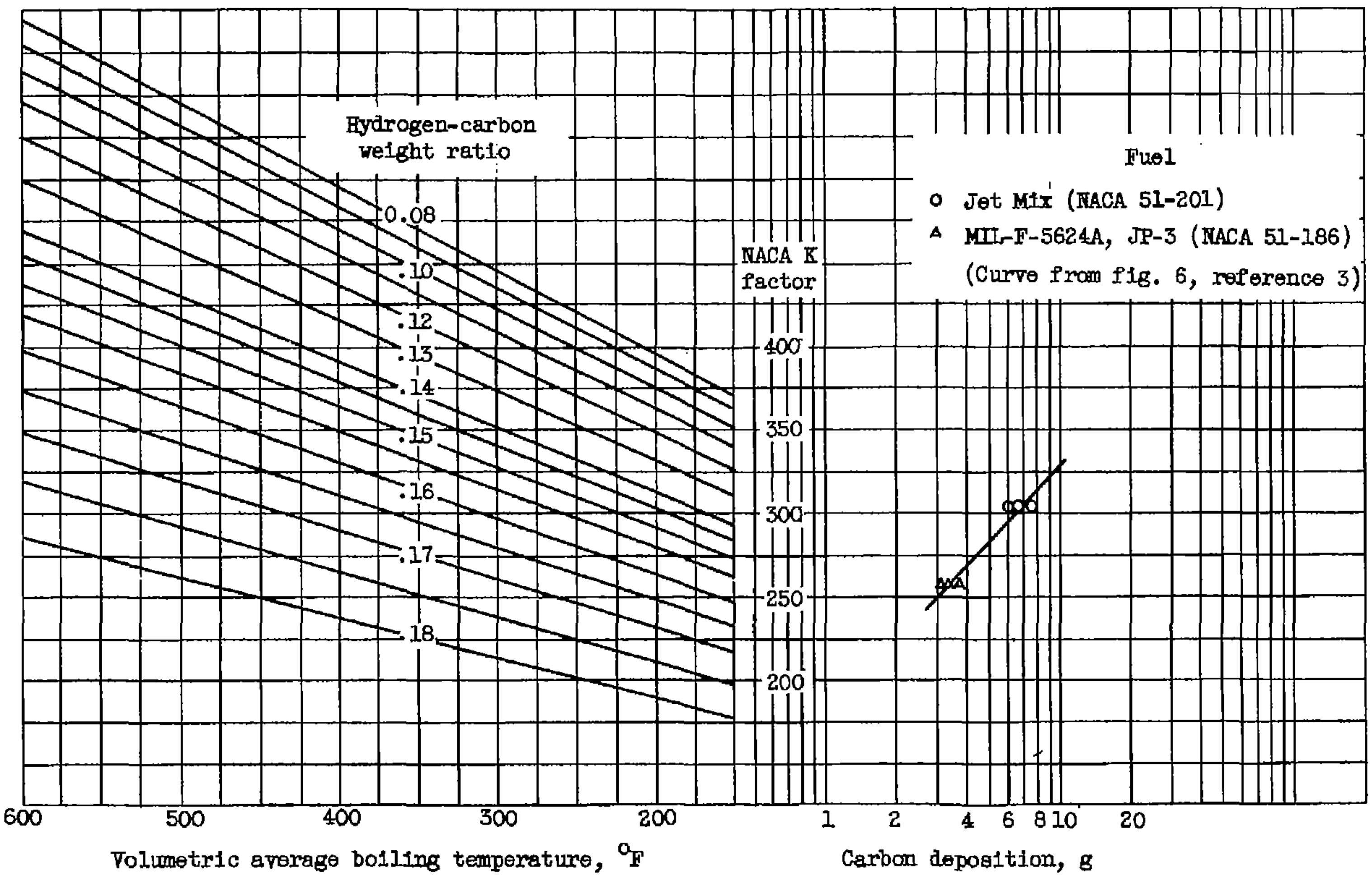

Figure 4. - Carbon deposition of Jet Mix and MIL-F-5624A (JP-3) fuels correlated with volumetric average boiling temperature and hydrogen-carbon weight ratio in J33 combustor. Simulated engine conditions: altitude, 20,000 feet; engine speed, 90-percent normal rated; Mach number, 0.0; run time, 4 hours.

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